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Scaling, the Main Obstacle in Efficient Use of Geothermal Fluids

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ABSTRACT

When dissolved solids from the water precipitate and form solid deposits in geothermal plants and equipment, they affect the utilization of the geothermal resources. Solid deposition is a major problem in the harnessing of geothermal resources. To improve the efficiency of geothermal utilization, solid deposition must be prevented or controlled. This paper presents results from a research project aimed at the study of the composition and structure of depositions formed by direct heating utilization of geothermal waters. Firstly, the chemical composition of geothermal waters from three selected low-temperature geothermal wells was determined. The influence of the temperature on the composition of depositions was studied by using the speciation program, Watch. Then the deposits which appeared by geothermal water utilization were analysed, both chemically and structurally. There were made repeated tests with chemical inhibitors to attempt to control solid deposition. The results of the tests indicate that the inhibitors are efficient in controlling the scales even at low concentrations.

1. INTRODUCTION

Geothermal energy is generally accepted as being an environmentally benign energy source, particularly when compared to fossil fuel energy sources. Geothermal energy is becoming more extensively utilized in the world during the last few years. Compared to most other available domestic energy resources it has the advantage of being one of the most non polluting resources.

Geothermal fluids are often highly mineralized and may be corrosive, resulting in damage of the equipment used for production and the distribution system. Damage may occur either in the form of metal corrosion and deposition of scales. The composition and mineralogical structure of the scales formed depend on the chemical composition of the geothermal water, the temperature of water and the composition of the material used for the equipment and in the distribution system. The purpose of this work was to study the relationship between the chemical composition, the temperature and the type of scales which can appear when geothermal water of different types is used for heating. Another aspect was to study the effectiveness of special chemical inhibitors to prevent scaling in the geothermal waters by utilization.

In this paper there were studied three low-temperature geothermal wells with varying properties, one from a Romanian geothermal field and two from Icelandic fields. The wells are: Sacuieni-4058 from Romania and SN-4 and LA-2 from Iceland.

In the Sacuieni geothermal reservoir seven drillholes were drilled prior to utilization. The production well 4058 has an artesian flowrate of 15 l/s and a wellhead temperature around 78-84^{0}C. The geothermal energy of this well is utilized for heating of greenhouses. Scaling problems inside the casing of the well have been reported from the beginning of production up to the present. The Seltjarnarnes geothermal field is located within the town Seltjarnarnes, one of the suburbs of Reykjavik and is located a few tens of meters away from the coast. A total of twelve wells have been drilled by now in the field, where of four are production wells. Well SN-4 is a production well drilled at 2025 m depth. All the wells have at least three feed zones of different temperature and salinity of the water (Kristmannsdóttir and Tulinius, 2000). Mixing of water from the different feed zones within a well may cause supersaturation of the water with respect to some minerals. The scaling potential increases with increasing temperature difference between the feed zones. Geothermal water produced by SN-4 is used for space heating by heat exchangers installed in each house. The geothermal resource of Sudureyri, located in the north-western part of the country is produced by two production wells. One of them is well LA-2 drilled to 684 m depth. Water is pumped with an average flowrate of 10 l/s, being used for house and commercial space heating, a swimming-pool and for fish drying. The wellhead temperature is around 64-68^{0}C. There have been recorded some scales in the distribution system and the water is corrosive for steel due to high oxygen concentration.

2.EXPERIMENTAL PROCEDURES

2.1 Water Analysis

Geothermal waters from the wells: 4058, SN-4 and LA-2 were sampled and analysed by standard methods for the Icelandic (Stănăşel, 1996) and Romanian labs (Stănăşel et.al., 2006). The procedure used in Romania was different for some components than the methods used in Iceland.

2.2 Scaling Prediction

The solubility of most minerals declines by decrease of the temperature of geothermal water, resulting in scale deposition. In order to predict the potential danger of scaling and corrosion, the Watch simulation program (Bjarnason, 2005) was used to calculate saturation indexes for several minerals. Based on the chemical composition of the water the program can calculate the ionic activity Q corresponding to different minerals and compare it with the theoretical solubility K of the respective minerals both at the measured temperature of the waters and at lower temperatures recorded by the utilization of the geothermal water. A positive value for the saturation index (log Q/K) of a mineral means that the solution is saturated with respect to that mineral and theoretically it could start to precipitate, depending also on kinetics of the process.

2.3 Analysis of Depositions

During the exploitation of these wells, scales have been encountered inside the wells and in the surface construction. The solid depositions were sampled and analysed. The scale from Săcuieni was chemically analysed by using analytical methods (Stănăşel et.al., 2006). In order to make these analysis the sample was first disintegrated.

The solid samples were thermogravimetric analysed as well as by X-Ray diffraction. The thermogravimetric analysis was made by the use of a Derivatograph Q-1500D. The sample was grounded very fine and it was heated up to 1000^0C with 10^0 / minute. X-Ray diffraction (XRD) and X-Ray fluorescence (XRF) studies on the solid samples were made in Orkustofnun laboratory from Reykjavik. In order of getting information about the crystals in the solid samples, the XRD studies were made by using KαCu radiations. A qualitative analysis (XRF) for the sample from SN-4 was made to determine which elements were presented in a specimen. There was used a silver anod in the analysis. The light elements were determined by using potassium phtalate and the heavy elements with litium fluoride. Analysis to gain a semiquantitative appraisal of their concentration by scanning electron microscopy (SEM) were made as well.

2.4 Tests with Chemical Inhibitors

In order to measure the ability of additives to control calcium carbonate deposition (Armannsson, 1989), a laboratory test was made as well as an onsite test with chemical inhibitors. Geothermal water from well 4058 was placed in a water bath at 82^0C for the duration of one hour. Calcium carbonate was found to precipitate from this water. In the next runs there were tried additions of sodium tripolyphosphate and VAMA (ammonium salt of the copolymer of vinyl acetate with maleic anhydride) to control the deposition of calcium carbonate.

The onsite test with chemical inhibitors was performed on well LA-2 in Sudureyri geothermal field, Iceland. A polyphosphate produced by Nalco firm was injected into the well as inhibitor. The concentration of inhibitor was modified according to the results obtained in each run. Before using the inhibitor and after each change of concentration, water samples were taken for chemical analysis. The samples were analysed by atomic absorption spectroscopy to determine the calcium content of the geothermal water.

3. RESULTS AND DISCUSSION

3.1 Water Analysis

The chemical data (Table 1) show that sodium, chloride and carbon dioxide are in high concentrations in the geothermal water from Săcuieni. The high carbonate content may affect scale formation. The geothermal water from SN-4 can be characterized as sodium-calcium-chloride water. The high salinity of the water is assumed to be caused by the infiltration of seawater into the geothermal system. The presence of hydrogen sulphide combined with the large amount of chloride may induce a corrosion process within the pipes. Geothermal water from LA-2 is sodium-sulphate-chloride, but the mineral concentration is lower as compared to the other wells studied. The silica content of SN-4 is high, so deposition of silicate minerals from the water could also be expected. All the waters studied are alkaline, especially the water from Sacuieni.

Table 1. Results of Geothermal Water Analysis

well	4058	LA-02	SN-4
pH/20 °C	8.2	9.7	8.3
Tot.carb. as CO_2	2085	9.1	8.4
SiO_2	56	60.9	112.9
B	52.5	0.06	0.23
Na	1620	90.6	622
K	21.2	0.88	14.3
Mg	4.2	0.011	0.73
Ca	17.2	8.7	461
Fe	0.08	0.008	0.008
SO_4	12.8	78.1	276
Cl	920	56.7	1510
F	-	0.41	0.58
H_2S	-	0.025	0.13
Al	-	0.045	0.009
TDS	7020	390	2966

3.2 The Temperature Influence on the Composition of Depositions

Using data from Table 1, log solubilities for the minerals were calculated by the Watch program. The program also reports the theoretical log K by temperature for the corresponding minerals, which were combined with the calculated results for log Q to plot the saturation indexes (log Q/K) against temperature for different minerals.

The log Q/K diagram for water from the Sacuieni well 4058 (Figure 1) indicates a supersaturation with respect to talc, chrysotile, calcite (Arnorsson, 1989) and quartz at the measured temperature. The water is in equilibrium with chalcedony. By cooling, the water is highly supersaturated of calcite with saturation index for calcite around one, so scaling problems with calcite can be expected. Supersaturation with respect to magnesium silicates increases sharply with temperature, but still there would hardly be expected deposition of such minerals. The supersaturation appears to increase slightly by cooling, which is contrary to what one would expect. The diagram does not reflect any distinct equilibrium temperature for the reservoir.

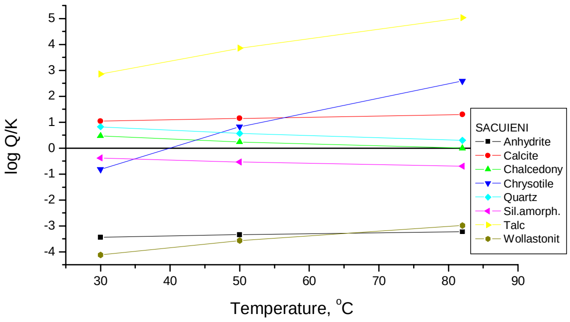

Figure 1: Log Q/K vs. temperature for geothermal water from well 4058

In the diagram for water from SN-4 (Figure 2) many of the minerals are in equilibrium at different temperatures in the temperature interval 65-85^0C. The water is close to saturation with calcite. Epidote and talc are supersaturated at the measured temperature, but those minerals would hardly be expected to create scaling problems. At the wellhead temperature the saturation index for magnetite is very high and if the temperature of geothermal water were to decrease during utilization, magnetite would still remain supersaturated. We can therefore expect steel corrosion to occur. Several minerals are noticed to become supersaturated at low temperatures, but no scaling is expected to occur, except for calcite if the water boils or pH is sharply elevated by some other means. The lines in Figure 3 displaying log Q/K against temperature for water from well LA-2 in the Sudureyri geothermal field are scattered and indicate no definite equilibrium temperature. It may be explained by an increasing influence of a colder aquifer in the production water. At the measured temperature most minerals are undersaturated (amorphous silica, adularia, wairakite), saturated (magnetite, prehnite, zoisite, microcline) or near the saturation line (calcite).

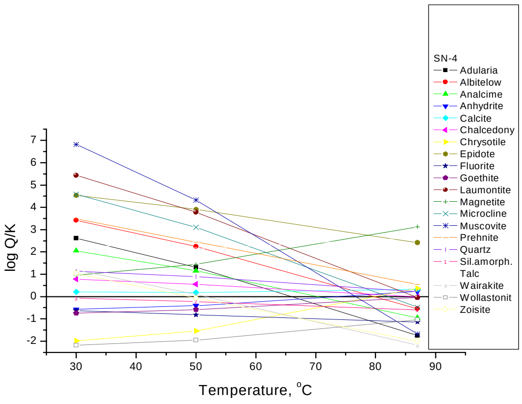

Figure 2: Log Q/K vs. temperature for geothermal water from well SN-4

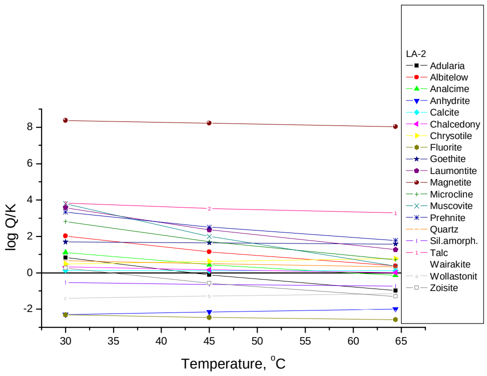

Figure 3: Log Q/K vs. temperature for geothermal water from well LA-2

3.3 Studies of Solid Depositions

A severe scale formation was removed from the pipe inside well 4058 during summer time, when the production was stopped. The results of the chemical analysis of the solid scale consist of: 53%CaO, 2.3%MgO, 1.1%Fe_2O_3 and 43.5%calcined loss, showing that calcium is the main element of the solid deposition from Săcuieni. The solid sample was analysed by thermogravimetry, (Figure 4) showing a decomposition process starting slowly at about 695^0C and reaching maximum at 950^0C. The mass loss is about 44% in the range of temperatures $695\text{-}950^0$C. This is characteristic for the loss of carbon dioxide from calcium carbonate. XRD analysis of the sample (Figure 5) indicates the presence of calcite and magnesium carbonate crystals in the solid sample. Taking into account the chemical analysis it means that the solid deposition consists mainly of calcite, the magnesium carbonate being in very low amount. The iron content must be due to a slight corrosion process.

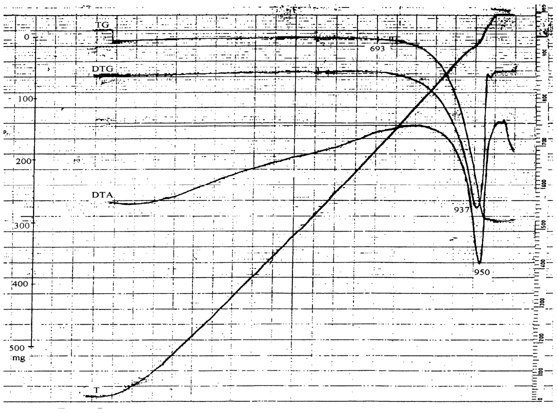

Figure 4: The thermo-gravimetric diagram for solid deposition from well 4058

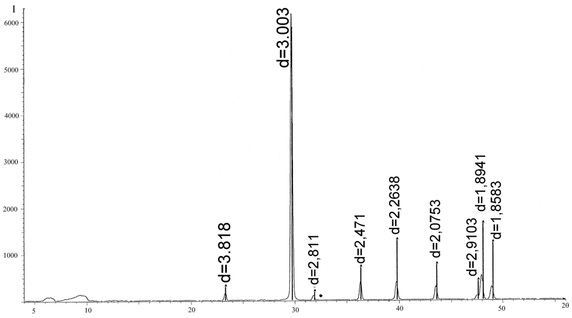

Figure 5: The XRD diagram for solid deposition from well 4058

A scaling monitoring device which had been within the pipeline from well SN-4 for about two years, was removed and analysed. In a preliminary inspection by microscope there were noticed some white formations, a trace of some yellow, brown and metallic coloured deposits. The brownish deposits indicate that corrosion had been induced. The solid sample was removed from the surface of the scaling device and subsequently analysed by X-Ray diffraction and XRF methods. The obtained XRD diagram (Figure 6) shows that magnetite crystals occur in the sample. The XRF diagram (Figure 7, a) indicates the presence of excessive Si and some Fe. The diagram also displays (Figure 7, b) the presence of Cr, Ca, Ti, Cu and Zn. The existence of Fe, Cr, Ti, Cu, Zn does witness an ongoing corrosion of the pipe. The other elements (Ca and Si) are constituents of the depositions formed by precipitation from geothermal water.

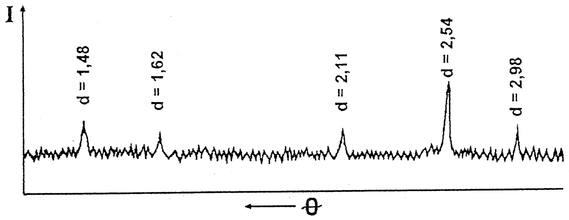

Figure 6: The XRD diagram for solid deposition from well SN-4

The solid sample was also analysed by SEM as shown in Figure 8. Fe due to corrosion of the pipe can be observed as well as Si due to deposition. Traces of Ca, Mg and S were seen, which indicates depositions of minerals containing Ca and Mg. In view of the yellow formations observed in the preliminary inspection, one would suspect deposition of iron sulphide. Traces of Cr probably originate from the pipe material.

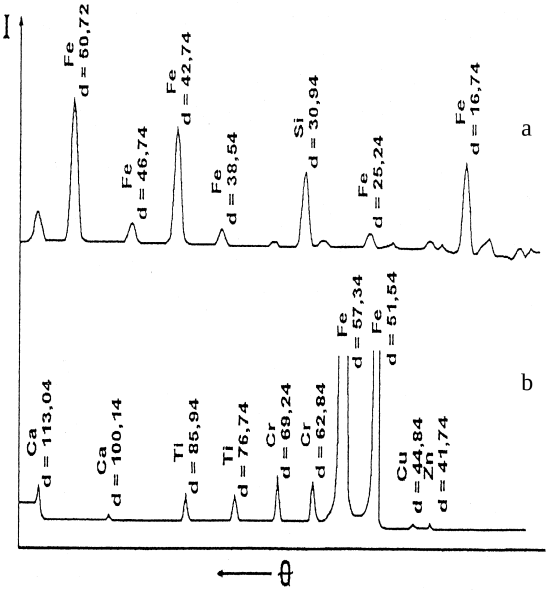

Figure 7: The XRF diagram for solid deposition from well SN-4

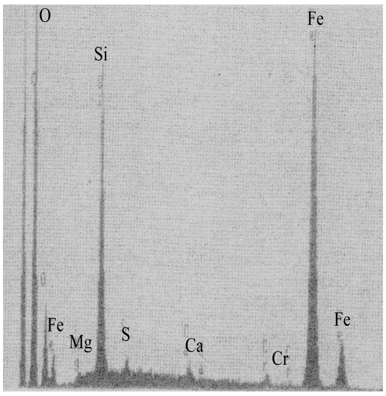

Figure 8: Electron microscope analysis of the sample from the surface of the scaling device

A sample of solid depositions which were formed during geothermal water utilization from well LA-2 was also studied. An XRD analysis (Figure 9) of this sample indicated calcium carbonate crystals primarily as calcite and some aragonite. There were noticed crystals of sodium chloride, probably due to infiltration of seawater in the upper layers of the reservoir and an evaporation of the fluid on the surface has left a small amount of NaCl from the water.

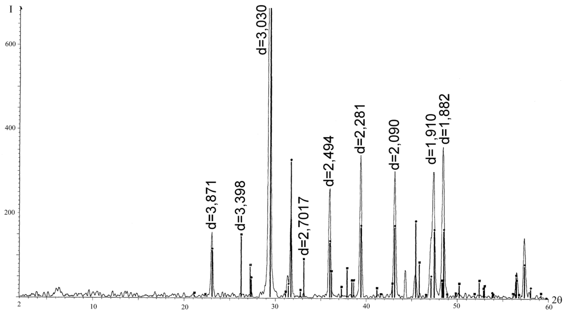

Figure 9: The XRD diagram for solid deposition from well LA-2

3.4 Tests with Chemical Inhibitors

Results from the laboratory test on geothermal water from well 4058 from Săcuieni by adding different concentrations of tripolyphosphate and of VAMA additives were used to generate the performance profile in Figure 10. The experimental results at those static conditions indicate that the tripolyphosphate additive can be useful to prevent the precipitation separation of calcium carbonate from water with a minimum dosage of 6 mg/l. As compared, the VAMA additive can give rather good results in preventing precipitation with a higher concentration of additive, exceeding 15 mg/l/.

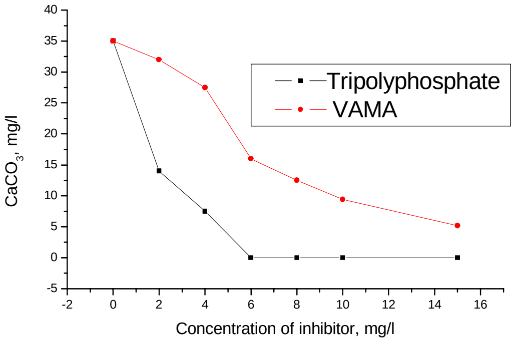

Figure 10: Deposition control with inhibitor in static conditions

In spite of supersaturation in well SN-4 from the Seltjarnarnes field very low amount of scale deposits were formed during two years production of the well. Therefore, experimental treatment with inhibitors was not considered necessary.

Selected laboratory results after injection of a polyphosphate as inhibitor into the well LA-2 are illustrated in Figure 11.

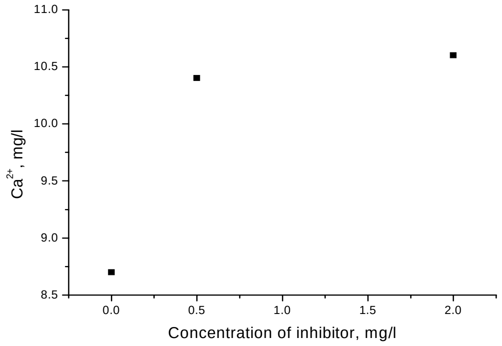

Figure 11: Deposition control with inhibitor in dynamic conditions

As shown, a very low calcium concentration is measured in the untreated geothermal water. By the use of the additive, the calcium concentration in water increases in accordance with the concentration of the inhibitor. This illustrates that the inhibitor maintains the calcium in a soluble form and prevents the formation of calcium carbonate deposits. There can be used as low concentration of additive as 0.5 mg/l with good results. Using a higher concentration of additive appears of no use as unsignificant differencies in calcium concentration are noticed by increased concentration of additive. By the use of additive down to 0.5 mg/l there was not recorded any scaling.

CONCLUSIONS

The geothermal wells selected for the present study have waters displaying a complex chemical composition depending on the aquifers and geological conditions in each of the geothermal systems. All of them may have a potential for scale formation due to either high salinity, total carbonate or mixing of different aquifers.

The chemical composition of the geothermal waters can be used to predict possible scaling and corrosion problems at changing temperatures and conditions. Based on the chemical data of the geothermal waters, the Watch simulation program by calculating the saturation index for many minerals is a useful tool to pinpoint the minerals which can possibly form depositions at the wellhead temperature and at consequently lower temperatures reached during utilization. Analysis performed of the solid depositions removed from pipes and scaling monitoring devices connected to the wells studied, showed similar precipitates as predicted by calculations on the respective waters by the Watch program.

After chemical and structural analysis the solid sample from Săcuieni, was found to consist of calcite, traces of magnesium carbonate deposits and some content of iron, probably due to corrosion. The structural analysis of depositions from SN-4 showed that at the wellhead temperature the deposits are formed by an amorphous phase consisting of complex silicates, carbonates and metal sulphide in small amount as well as a crystalline corrosion product, magnetite. The XRD analysis of the solid sample from LA-2 indicated the presence of calcium carbonates in large amounts.

The structure of the depositions from the studied well from Romania is very similar to those from well LA-2 from west Iceland. These deposits were so severe, that a method to combate scaling was much needed. For this purpose there were made some laboratory experiments in Romania, giving very promising results in terms of scale prevention. Those lab results can be easily upscaled to field conditions. In Iceland a successful chemical inhibition test was carried out in dynamic conditions by injecting the additive into the well in different concentrations and monitoring the results. The efficiency of additives like polyphosphates to prevent calcium carbonate scale was successfully demonstrated by the test.

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